SCIENCE

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THE VITAL EQUILIBRIUM AND THE NERVOUS SYSTEM.

IT is noticeable that there has been a tendency on the part of our most thoughtful working biologists, especially such as are equally equipped for the philosophical and biological aspects of cellular biology, to seek some avenue of return to the vitalistic point of view. It has become sufficiently plain that the most conspicuous triumphs of histology, even in the domain of cytology, have rather reduced than increased the probability of securing an explanation of vital phenomena and specific heredity and integrity from the study of structure alone. A strong tendency is visible toward a dynamic point of view. We believe that a consistant application of a dynamic hypothesis is destined to prepare the way for greater advances, not only in interpretation, but also in practical applications of biological principles. When we come to regard the visible structural data of histology as expressions of dynamic processes rather than the causes of these processes, and when we have agreed to apply other criteria than that offered by materialism to the phenomena of heredity, we may be able to shake ourselves free of preconceptions that have done much to retard the normal development of both biology and psychology. It is true that a strong prejudice exists against the dynamic method because of the belief that it tends to limit research and

thus deprives science of its necessary footing upon observation. If the criticism be just as applied to those who have sought to escape from the crudities and limitations of materialistic theories, it certainly should be recognized that there is no reason why the believer in dynamism should not scrutinize the pictures presented by histology as carefully as his colleague who ascribes to matter all the phenomena that science recognizes in cellular biology. In fact, the dynamist should have greater interest in the details of such appearances, for he may believe that every curve must be the function of a dynamic problem and that every change is the resultant of the composition of forces which are the very realities with which he has to do.

In no field have the results of too implicit reliance on the structural categories worked more plainly to retard progress than in neurology. It seems to be assumed that after nervous mechanisms were differentiated in the animal kingdom all other parts of the body at once and forever lost their original quota of what may be termed the power of vital equilibrium. When the preeminent adaptation of the nervous system to the function of correlation was recognized it was not unnatural that the inherent tendency to vital coordination on which the coherence of the body depends during its entire life should be minimized or ignored. Especially when the application of the methylen blue and silver impregnation revealed a hitherto unexpected wealth of nervous connections, it was natural to think of the body as linked together by a complete nervous mechanism to such an extent that all coordinations are dependent on the persistence of the nervous continuum. Even admitting the practical ubiquity of nervous elements within the body, sundry curious coordinations remain to be explained apart from any known basis of nervous control. It may suffice to mention the following: It is evident that during the embryonic stages of higher animals, as well as throughout the life of many lower forms, a very complete and active coordination and trophic equilibrium exists, which suffices to superintend the structural differentiation and for the maintenance of the body under circumstances where nervous influence as such is excluded. Again, the wandering cells and blood corpuscles, and probably part at least of the chromatophores, are certainly coordinated under vital control, though not under direct or permanent nervous influence. Lastly, the vegetable kingdom furnishes us with structures scarcely less complicated than those of higher animals, but, in spite of the high degree of specialization and individuality and the perfection of the correlation of part with part, nothing analogous to a nervous system has been discovered. Yet in plants there is a remarkable condensation of the characters of the individual in every individual part, in so much that the smallest fragment of one of the Bryophyta may reproduce a new individual. These commonplaces of biology are cited to illustrate the fact that the body of a plant or animal may be very completely coordinated, and each part may be stamped in some way with the influence of the whole body without the necessary participation of the nervous mechanism.

On the other hand, we have the best of evidence that all nervous action is trophic, and that processes going on in extra-neural tissues are influenced by nerve currents, and that neural equilibrium is also influenced by the somatic-vital processes of cells among which the termini of nervous arborizations ramify. The conclusion is apparently warranted that while the nervous system is, in a sense, super-added upon a self-sufficient somatic equilibrium-system, and, accordingly, the higher nervous processes are, from the stand-point of the body, epiphenomena, yet there is no sharp line of demarkation between them and the somatic forces.

The search for the structural evidence for such coordination cannot be said to have been very successful, though the statements of numerous observers respecting 'intercellular bridges' and other means of communication have served to keep alive a spirit of expectancy. It is the purpose of this paper to offer an illustration of a structural basis for vital or somatic coordination which seems, so far as a cursory glance at the literature enables me to judge, not to have received any adequate interpretation. It may be said in advance that the prevailing idea that the body is made up of close ranks of cells set immovably in tissue as stones are cemented in a wall is applicable to comparatively few parts of the body. Any one who has observed the structure of the embryonic body, say of a vertebrate, must have been struck with the fact that the interspaces between the embryonic tissue are wonderfully permeable to the invasion of proliferating and migrating cells of all kinds, so that the developing nerve, for example, has no difficulty in reaching its destination as it grows by progressive proliferations at its tip. In the adult the brain offers an illustration of a similar permeability, and the effectiveness of the organ depends, in no small degree, upon the fact that nutriment-bearing cells make their way with great freedom among the neural elements. There can be no doubt that the brain cells are undergoing constant renewal, and it is now admitted that the degenerations observed in the cortex of paralytics can be duplicated in kind in the relatively normal brain.

Our own present illustrations are derived from the preparations of the skin of the axolotl and the horned toad, two subjects sufficiently different from each other to warrant us in believing that structures found in both are present quite generally, a least within the two classes they represent. The skin of the Amphibia has been so extensively studied that it may appear incredible that conspicuous structures should have escaped notice, but even should the details not prove entirely new the illustration is an apt one for my present purpose.*

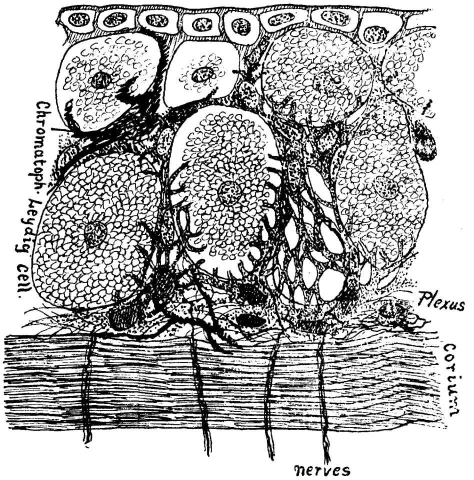

FIG. 1. Section through skin of axolotl hardened in Merkel solution ½, stained with picrocarmine and hæmatoxylin. Nerve fibres, passing through the corium, enter a plexus demonstrable by methylen blue, and non-medullated fibres ascend to attach themselves to the naked intercellular protoblasts which support the coarse reticulum. One Leydig cell is not cut by the section and over its surface the meshes are entire; in other cases only the cut ends are shown by focusing at different depths.

It happened that in the search for a histological method for the study of the cytoplasm various modifications of the chromic and osmic acid fixers were employed, and it was noticed that certain combinations of chrom-acetic and platinic chloride, when diluted with alcohol, gave remarkably fine fixation of protoplasmic structures without impairing their susceptibility to stains to the extent that osmic acid preparation notoriously does. After-treatment with hæmatoxylin and either fuchsin, or, still better, picrocarmine gave exceedingly distinct contrast stains. The protoplasmic structures

*They have been seen, as indicated beyond, but wrongly interpreted.

take on a deep red color, as do the nerve fibres and connective elements, and this contrasts finely with the deep but transparent purple of the nucleary structures. In such specimens we were gratified to find that the two distinct elements in the skin are clearly differentiated. The large (Leydig) cells are perfectly fixed, the cytoplasm displaying a complete vesicular structure, such as an examination during life under favorable circumstances sometimes reveals. Nucleary figures are clearly marked and shrinkage seems almost absent. The antagonistic effect of chromic acid and alcohol in the presence of a rapid fixer like platinic chloride seems here to have proved of great advantage. Compared with the best preparations by Flemming's method the latter appears at a great disadvantage because of shrinkage phenomena. The later method, however, is a valuable check because by it the contents of the cytoplasmic vesicles are demonstrated as dark globules, giving rise to the familiar coarsely granular appearance and giving evidence of a chemical difference between the vesicles and their contents. But sufficiently good specimens by either method, but especially such as were prepared by the alcohol modification of Merkel's fluid, showed that every individual cell of the larger series is wrapped in a delicate protoplasmic network which can be resolved into processes from protoblasts occupying the interstices among the Leydig cells. Often the meshwork can be traced from one cell over its neighbor, and there can be no doubt that the processes from separate protoblasts unite to form the general reticulum. It is also true that the protoblasts lie in all parts of the epithelial layer, both ectad and entad of the Leydig cells.

As already mentioned, this reticulum has been noticed by Paulicki in the Archv. f. mikroscopische Anatomie, Vol. XXIV., 1884, but in the paper referred to the maial had evidently been greatly shrunken, and as the result it appeared as finer, shriveled network, and the absence of double staining may have failed to reveal its protoplasmic nature. The author, although his drawings show the fibres embracing the Leydig cells and passing from one to the other, describes them as varicosities on the wall! Such a view is quite impossible after an examination of the specimens. It might be suggested that the naked protoplasmic network is simply a part of a continuous film covering these cells, and this possibly may be the case during the life of the tissues, though we incline to the belief that the reticular structure is rather the expression of streaming notions.

The variability in the size of the meshes speaks for the latter view, as do the distortions in parts of the skin that were folded or stretched during hardening. The meshwork is most pronounced in thicker parts of the skin, especially along the sides and back. Whether it is the function of this reticulum to supply nourishment to the large extra-vascular (Leydig) cells, or to afford the basis for a more direct coordination than would otherwise be possible, it would, in either case, remain true that trophic influence over the less plastic cells would be an essential part of its function.*

* Both Fitzinger and Paulicki (Arch. f. mik. Anat. Band XXIV., 2.) describe these bands as thickened ridges or varicosities of the walls of Leydig's cells, and the former even goes so far as to suggest that these 'rib-like thickenings of the cell-membrane serve for attachment of the intercellular bridges.' Paulicki says 'it may be assured that this meshwork is occasioned by a rib-like partial thickening of the cell-membrane,' though he mentioned that the meshes stain like the protoplasm. It is not strange that the methods and optic aids then at disposal should permit an error of this kind, but it is peculiar that the same writer should go on to say that he 'observed that a continuous frame-work extended over numerous Leydig's cells' and that similar meshes continued to adjacent epithelial cells. He also noticed, without discovering its significance, the fact that the epithelium cells are without walls, that is, are 'protoblasts.' In our specimens it is possible to find appearances

It is, in any case, of the highest importance to determine the rôle played by the nerves in this connection. In sections stained with hæmatoxylin and picrocarmine there is no difficulty in tracing the nerve fibres through the corium, for these fibres are medullated and stain conspicuously, but in the layer of chromatophores below the epithelium the fibres lose their sheaths and seem to blend with the bases of the protoblasts, giving rise to the meshwork just described. The fibres can often be traced to the immediate vicinity of the nuclei of these cells, but because of the lack of contrast between the protoplasm of the cells and the nerve fibres it is difficult to determine their respective limits. Methylen blue preparation stained *intra vitam*, in which only the nerve fibres are selectively impregnated, enable one to trace the medulated nerve fibres through the corium and into a subepithelial network, or in some cases into cells resembling small non-pigmented chromatophores, but which may be ganglion cells of the plexus. From the plexus, non-medullated fibres rise into the vicinity of the nuclei of the protoblasts and appear to end in knobs as described by Bethe. The results of the methylen blue method are to be interpreted with caution, but there can be no doubt that the opportunity for nervous control over the reticulum or pericellular network is most complete and extensive. The nerve plexus entad of the corium is most distinctly stained in methylen blue preparations and is of exquisite delicacy and supplies the fibres to the blood vessels and chromatophores.

An entirely different type of nerve ending is found in the skin of the head. The sense buds give with methylen blue the usual appearance of a perigemmular set of fibres, but it seems to us that there is too great haste apparent on the part of those who have abandoned the classical results of strictly histological methods which have demonstrated an entirely different type of intragemmal endings. It is customary at present to deny the ending of peripheral nerves in cells on principle, except in the case of the olfactory nerves. To be consistent, the same objections would prevent us from recognizing the olfactory cells as true cellular endings for the theoretical considerations which have led authors to set apart the olfactory nerve as distinct and different from other sensory nerves are, it is believed, based on false premises. In fact, the olfactory nerve is simply a persistent embryonic nerve, and its fibres are, like the early stages of all nerves, moniliform series of cells which have proliferated from a common source. Each segment of an ordinary nerve fibre is shown by embryonic and pathological evidence to be derived from a neuroblast united to its neighbors at either extremity. The nuclei of the sheath of Schwann are morphologically the nuclei of the neuroblasts which are represented in the segments to which they belong. In the second type of nerve endings it is possible to take either one or two alternatives. Either the terminal cell is an independent neurocyte developed *in situ*, or it is a somewhat differentiated segment of the nerve itself. There are some reasons for accepting the latter alternative in the present case. Such endings are best seen in the skin of the head of the tree-frog. Here it is easy to trace the nerves through the corium in bundles of three or more, and the fibres pass without interruption through the chromatophore-layer and lie in a special cavity of the skin in such a way that their tips end free in a pore connecting with the exterior.

The terminal portion is continuous with

like those figured by Paulicki, but we also find instances where the meshes of the network are broad bands rather than rib-like bodies and their continuity with the epithelium cell-protoplasm is perfectly obvious.

the medulated fibre which preserves its sheath up to the point where its large nucleus appears. The latter occupies the lumen and is quite conspicuous, while ectad of it the fibre is reduced to a sensory rod with small rigid styles or cilia at the apex. Such termini are quite generally distributed over the skin of the head and take the place of the buds found in other types. The double staining is exceptionally good, and teased preparations produced by pressure on the cover glass permit the isolation of the termini and their study under immersion lenses. It seems probable that the differences of opinion which still prevail in this matter are the result of the partial results of the different methods, and that the truth will be reached by an intelligent employment of the data from them all. In conclusion the writer desires to acknowldgee the substantial assistance rendered, especially in the laboratory manipulation on which this paper is based, by his friend Mr. G. E. Coghill, in collaboration with whom a more detailed report of the histological processes and results may be expected in the *Journal of Comparative Neurology* at no distant date.

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SOME EXPERIMENTS ON ANIMAL INTELLIGENCE.

THE results of a recent investigation on animal intelligence, the details of which are about to be published,* seem to be of sufficient general interest to deserve an independent statement here. The experiments were upon the intelligent acts and habits of a considerable number of dogs, cats and chicks. The method was to put the animals when hungry in enclosures from which they could escape (and so obtain food) by operating some simple mechanism, *e. g.*, by turning a wooden button that held the door, pulling a loop attached to the bolt, or pressing down a lever. Thus one readily sees what sort of things the animals can learn to do and just how they learn to do them. Not only were the actions of the animals in effecting escape observed, but also in every case an accurate record was kept of the times taken to escape in the successive trials. The first time that a cat is put into such an enclosure, some minutes generally elapse before its instinctive struggles hit upon the proper movement, while after enough trials it will make the right movement immediately upon being put in the box. The time records show exactly the method and rate of progress from the former to the latter condition of affairs. A graphic representation of the history of six kittens that learned to get out of a box 20×15×12 inches, the door of which opened when a wooden button $3\frac{1}{2}$ inches long, $\frac{7}{8}$ inch wide, was turned, is found in the curves in Figure 1. These curves are formed by joining the tops of perpendiculars erected along the abscissa at intervals of 1 mm. Each perpendicular represents one trial in the box; its height represents the time taken by the animal to escape, every 1 mm. equalling 10 seconds. A break in the curve means that in the trials it stands for, the animal failed in ten minutes to escape. Short perpendiculars below the abscissa mark intervals of twenty-four hours between trials. Longer intervals are designated by figures for the number of days or hours. The small curves at the right of the main ones are, as the figures beneath them show, records of the skill of the animal after a very long interval without practice. This process of associating a certain act with a certain situation is the type of all the intelligent performances of animals, and by thus recording the progress of a lot of animals, each in forming a lot of each kind of associa-

* Animal Intelligence; An Experimental Study of the Associative Processes in Animals; *Psychological Review*, Supplement No. 8.